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AN ANALYSIS OF HAZE EFFECTS ON LANDSAT MULTISPECTRAL SCANNER DATA

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16. Abstract

The quality of satellite imagery used to identify field crops and estimate crop production can be adversely affected by haze caused by aerosol particles in the Earth's atmosphere. For example: (1) Early season changes in optical depth change brightness, primarily along the soil line; and, during crop development, changes in optical depth change both greenness and brightness. Thus, the existence of haze in the imagery could cause an unsuspecting analyst to interpret the spectral appearance as indicating an episodal event when, in fact, haze was present. (2) The techniques for converting Landsat-3 data to simulate Landsat-2 data are in error. The yellowness and none-such computations are affected primarily. (3) Yellowness appears well correlated to optical depth. Experimental evidence with variable background and variable optical depth is needed, however. (4) The variance of picture elements within a spring wheat field is related to its equivalent in optical depth changes caused by haze. This establishes the sensitivity of channel 1 (greenness) pixels to changes in haze levels. (5) The between-field picture-element means and variances were determined for the spring wheat fields. This shows the variability of channel data on two specific dates, emphasizing that crop development can be influenced by many factors.

With the Atmospheric Correction program ATCOR, it is feasible to reduce segment data from Landsat acquisitions to a common haze level and improve the results of analysis.

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AN ANALYSIS OF HAZE EFFECTS ON LANDSAT MULTISPECTRAL SCANNER DATA

Job Order 71-318

This report describes the Supporting Field Research Data Analysis activities of the Supporting Research project of the AgRISTARS program.

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PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is an 8-year program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources, which began in fiscal year 1980. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Agency for International Development, and the U.S. Departments of Agriculture, Commerce, and the Interior.

The work which is the subject of this document was performed in support of the Earth Resources Research Division, Space and Life Sciences Directorate, at the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., performed the tasks which contributed to the completion of this research.

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1. INTRODUCTION

Satellite-acquired imagery is used extensively in the Ariculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program, a cooperative endeavor of the National Aeronautics and Space Administration (NASA), the U.S. Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA, U.S. Department of Commerce), the U.S. Agency for International Development, and the U.S. Department of the Interior. This imagery, which is acquired primarily by the multispectral scanner (MSS) on board the Landsat Earth-observing satellites, is used to identify field crops and to determine the total area of each agricultural crop of interest.

The Earth's atmosphere always contains some level of aerosols; and, if the concentrations and sizes of aerosol particles are large, the quality of the satellite data can be altered significantly. Although the concentrations and sizes of the aerosol particles usually are small and do not have a significant effect on the quality of imagery acquired from the Landsat, it is desirable to determine what effect they have on the imagery analyzed in crop identification and estimation procedures.

During the Large Area Crop Inventory Experiment (LACIE), which preceded the AgRISTARS program, procedures were developed to analyze Landsat-2 and Landsat-3 imagery.

The LACIE analysis procedures included a visual examination of a series of images taken at intervals during the growing season of the crop being studied and applications of other analyst aids, such as crop growth-stage calendars and climatological data. Techniques were also developed in LACIE to minimize the effects of aerosols on the imagery produced from the Landsat data. This imagery is referenced as the product 1 image generated by the production film converter (PFC) system.

The Atmospheric Correction (ATCOR) program (ref. 1) was developed to correct Landsat data for the effects of haze, sun angle, and background reflectance.

The ATCOR program estimates the haze level of the atmosphere in a Landsat scene, which is expressed as the optical depth, tau (τ). In addition, other concentrations of haze can be simulated over a scene.

This paper reports on the effects of haze on the four Landsat channels and on certain linear combinations of the channels (greenness, brightness, yellowness, and none-such) that have been found useful for analyzing Landsat data. The greenness, brightness, yellowness, and none-such terms were introduced by Kauth and Thomas (ref. 2).

2. STUDY DESCRIPTION

In this study, a 5- by 6-nautical-mile (7- by 9-kilometer) area in Kingsbury County, South Dakota, designated as segment 1811, was selected as the area for analysis. This segment is one of the blind sites. Complete ground truth for these sites is provided by the USDA county agricultural agents. This includes a complete inventory specifying each field, crop, and land use within the segment. Also, 15 of the spring wheat fields in the blind sites were visited periodically, usually near the date of the Landsat overpass; and the wheat plant height, growth stage, and crop coverage were recorded. The period of analysis was the 1978 growing season, which was characterized by a wet spring that delayed planting 2 weeks to 1 month. Once the crops were planted, the development was normal. The spring wheat yield was estimated to be two-thirds of the normal yield.

The segment data, consisting of seven acquisitions of Landsat 1978 data (four from Landsat-2 and three from Landsat-3 as shown in appendix A), were processed using the ATCOR program. This program estimates the haze level τ using the data from channel 1. The estimated haze level is that which is homogeneous over the entire segment. In the seven acquisitions, the τ varied from 0.053 to 0.368. From the estimated τ and sun angle, the ATCOR program first determines average segment reflectance values $\bar{\rho}_i$ for each channel i. Next, ATCOR computes the coefficients $A_i(\tau',\theta,\bar{\rho}_i)$ and $B_i(\tau',\theta,\bar{\rho}_i)$, where θ is the sun angle and τ' is the optical depth of the haze level for simulation. The sun angle is not changed in the simulation.

Using equation (1)

$$\bar{X}_i' = A_i\bar{X}_i + B_i \tag{1}$$

where $\bar{X}_i$ is the mean for channel i, and $\bar{X}_i'$ is the simulated mean for channel i at the new τ' levels. Haze levels for τ' values of 0.0, 0.2, 0.4, 0.6, and 0.8 were simulated by the ATCOR program for each of the seven acquisitions of segment 1811. Equation (1) was applied to the field means of each of the 15 fields to get the simulated means at each of the τ' values.

The results of analyzing the simulated means from one of the 15 special fields, spring wheat field 3, are presented in this paper.

3. HAZE EFFECTS ON LANDSAT MSS CHANNELS

The four channels of the Landsat MSS span the following wavelengths: 0.5 to 0.6 micrometers, 0.6 to 0.7 micrometers, 0.7 to 0.8 micrometers, and 0.8 to 1.1 micrometers. The mean $\bar{X}_i$ and standard deviation SD_i in each channel i (table 3-1) were calculated for the 107 pixels in special field 3, and simulated field means were determined using equation (1). The simulated results found at two stages of wheat growth, emergence (day 115 in 1978) and near ripening (day 197 in 1978) are presented in figures 3-1 and 3-2, respectively.

Channel means for both dates increase in value with increasing τ. The means in figure 3-1 are characteristic of the emergence state (mostly soil); those in figure 3-2 are characteristic of a complete canopy of wheat (chlorophyll). The difference is especially seen in channel 3, where the vegetative influence increases the pixel value by a factor of about 2. Superimposed on the plots are standard deviations for each channel. These standard deviations are projected horizontally to relate to a variation in τ which would produce a similar size error. (This horizontal projection assumes a linear relationship which is not exactly true; however, the error values are valid enough to indicate the channel effect.) This shows that channel 1 is most sensitive to τ variations and that channel 4 is relatively insensitive to τ variations. That is, from the projection, a 0.2 variation in τ would change pixel values within the span of one standard deviation (σ) in channel 4 and would be near a span of 2.5 σ in channel 1 (fig. 3-1). This is consistent with the ATCOR haze model, in which the effect of haze is assumed greatest in channel 1.

Table 3-1 presents the within-field analysis of the spectral data in field 3. The variance of each channel is related to the changes in optical depth that can be seen.

The slopes of the channel 1, 2, and 3 curves in figure 3-1 are nearly the same, and a change in the τ level of each channel would have about the same effect on the channel means. Differing τ levels may account for some of the variation in channel means seen on consecutive acquisitions. In addition, the variation in

TABLE 3-1.- WITHIN-FIELD PIXEL MEANS FOR WHEATFIELD 3 (107 PIXELS) WITH VARIANCES RELATED TO OPTICAL DEPTH SPAN ($\Delta\tau$)

Day	Channel	Mean	Variance	$\Delta\tau$
115	1	21.0	1.9	0.12
	2	19.5	4.8	.22
	3	18.8	22.0	.54
	4	8.7	4.4	.76
197	1	22.0	2.1	.16
	2	17.5	4.4	.24
	3	53.0	22.7	>.80
	4	25.9	9.4	>.80

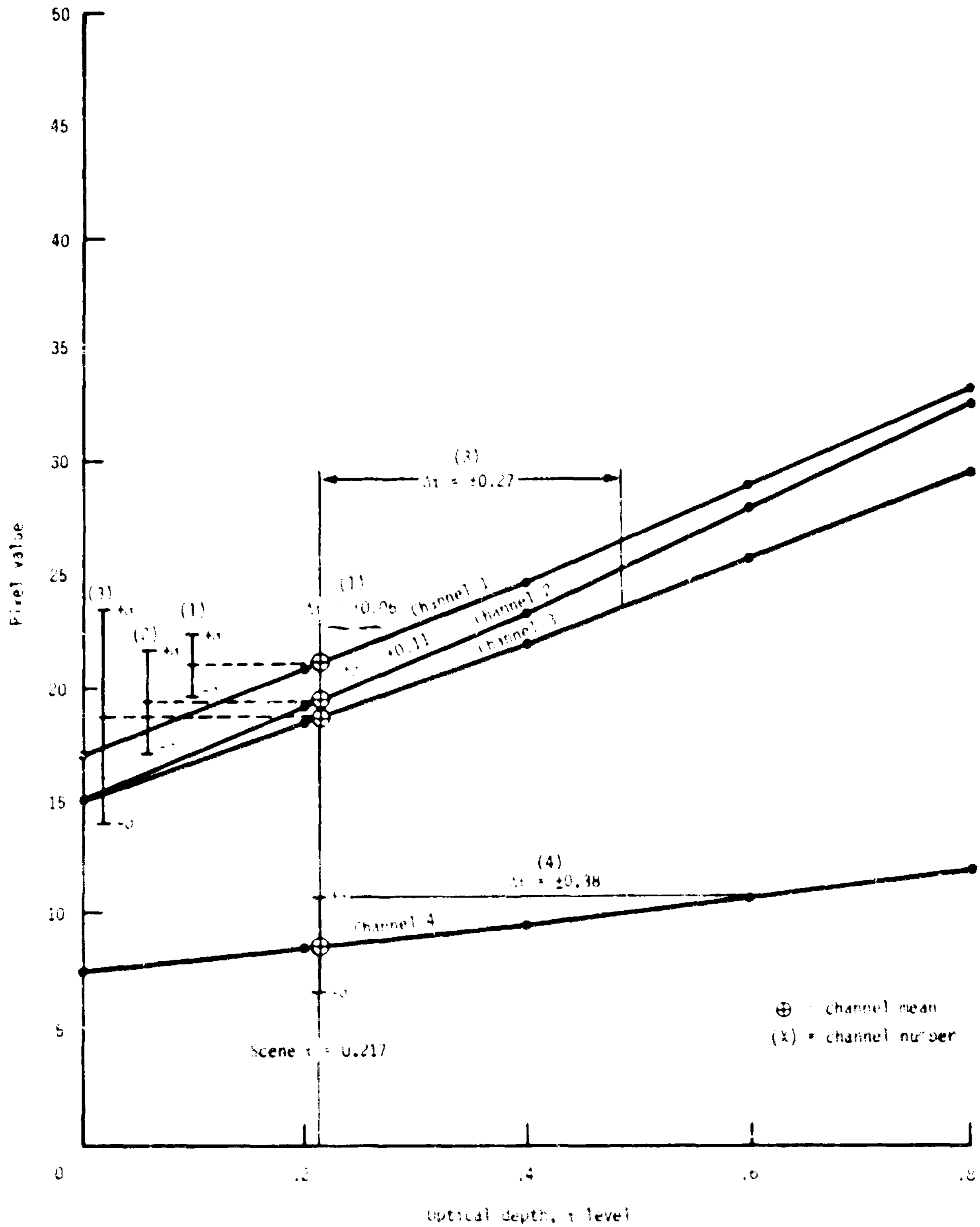


Figure 3-1.- Pixel values with increasing τ (day 115, near emergence).

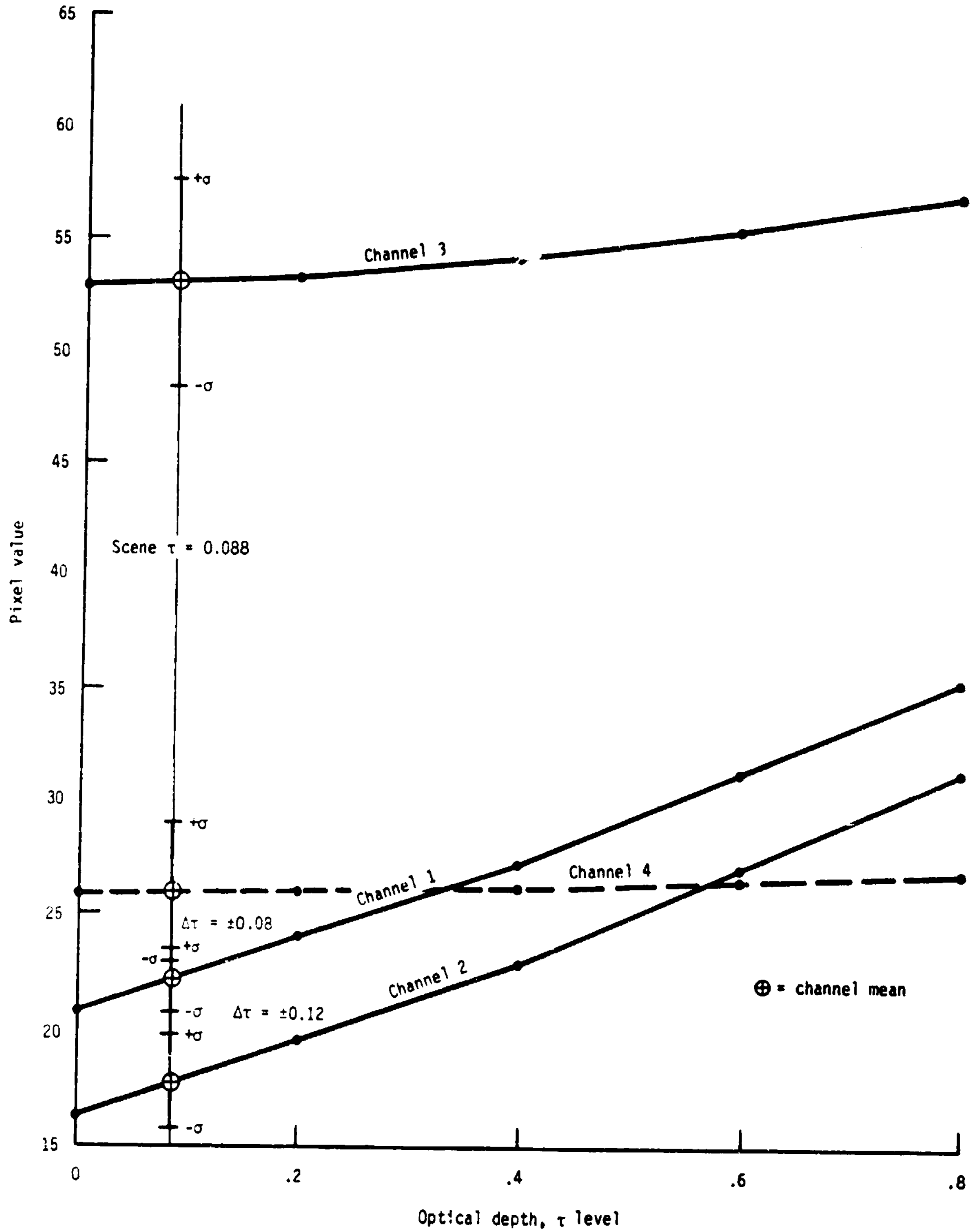


Figure 3-2.- Pixel values with increasing τ (day 197, near ripening).

channel means on consecutive acquisitions can also be the result of the difference in viewing angle from the spacecraft to the field. It is often possible to view a segment to the right of track on one day and to the left of track on the next day. Since the spacecraft passes a given latitude at the same time each day, the sun illumination of the field is almost the same. Thus, the difference between consecutive day observations is the viewing angle difference, which can be a maximum of 7° since the sweep angle of the MSS is 3-1/2° to both sides of nadir. It can be shown that this difference in viewing angle can induce as much as a 7-percent change in channel values in the same sun illumination cases. Rigorous normalization of data taken through an entire crop growing season would consider corrections due to differences in sun illumination, in viewing angle, and in atmospheric haze level.

The ATCOR program provides the technique to correct the pixel values of each channel for all acquisitions to eliminate the τ difference. Thus, as a first step to normalization, data adjustment due to τ differences should be performed before applying data analysis processes.

Using the channel means for each of the 15 spring wheat fields in the segment on two dates, day 115 and day 197, a between-field channel mean and a variance were computed. The results are shown in table 3-2. Data variations are expected because fields are in slightly different growth stages, have environmental differences, are subject to different cropping practices, and possibly may have a different concentration of haze above each. If one were to assume that all the wheat fields were in the same growth stage, had same rainfall, and had similar cropping practices, the variance of the field means for channel 1, as seen in table 3-2, can be attributed to the variation in haze over the fields. Since channel 1 is the most sensitive haze as compared to other channels, the small values seen here for channel 1, when compared to those of the other channels, indicate that the variability in haze is not due to haze. A case of large haze variability over the fields in a segment would find the channel 1 variance near that of channel 2. Since variability of haze over the fields in this case is small, the variation of the channel data can be attributed to one or a combination of the other effects listed above.

TABLE 3-2.- BETWEEN-FIELD PIXEL MEANS AND VARIANCES (15 FIELDS)

Day	Channel	Average of field means	Variance of field means
115	1	22.3	3.3
	2	22.0	10.8
	3	22.8	21.4
	4	10.3	4.0
197	1	21.4	.8
	2	16.0	2.0
	3	56.2	32.7
	4	27.7	8.4

The variations in haze over a segment which affect fields in one area of the segment more than those in another are not frequently considered. Currently, no techniques are available to study this variability in haze over a segment; however, several approaches are being formulated to investigate the variability of haze over a larger area than that of the 5- by 6-nautical-mile segment.

4. LANDSAT DATA TRANSFORMATION

It has been found that it is very useful to analyze Landsat data where the four channels of data are transformed into a single term. A linear transformation of the data (based on the Kauth transform, ref. 2) was performed to present the four channels of MSS Landsat data in terms of one of the following: greenness, brightness, yellowness, or none-such (appendix B). This transformation was developed for Landsat-2 data (ref. 3). Because of sensor calibration differences, Landsat-3 data are simulated as Landsat-2 data by applying the transformation derived by D. Wehmanen (ref. 4) and commonly referred to at NASA Johnson Space Center (JSC) as the "OSCAR" terms (appendix C).

The transformation(s) were applied to the means for special field 3. The means were derived from the spectral data sets (appendix A) which had been processed by the ATCOR program at each of the five haze-level optical depths. The computations were made for each of the seven acquisition dates, and the results are discussed in the following sections.

5. HAZE EFFECTS ON GREENNESS

The greenness transformation (appendix B) was applied to the mean of values from special field 3 derived from the spectral data sets at each of the five simulated haze levels. The results at two stages of wheat growth, emergence and near ripening, are presented in figures 5-1 and 5-2, respectively.

The contribution from each channel to the greenness and the greenness itself are plotted. The contributions of channels 1 and 2, which supply negative terms to the transform, exceed those of channels 3 and 4 (positive terms). This results in a negative sum (greenness) at the emergence stage. This sum becomes more negative with increasing τ. However, at the ripening stage, the positive contributions of channels 3 and 4 far outweigh the negative contributions of channels 1 and 2. This results in a positive greenness value. Again, this sum decreases in value with increasing τ.

Figure 5-3 shows the greenness profile through the wheat-growing year. Lines connecting the 0.0 τ and the 0.8 τ haze levels outline the limits of greenness on each acquisition day, showing the 0.2, 0.4, and 0.6 τ haze levels. The greenness of the field is plotted as an S on each acquisition day. Pertinent crop information is noted periodically in the legend to indicate the height of the wheat plant, its percent of coverage on the ground, and the Feekes crop stage. Each acquisition is labeled as Landsat-2 (LS2) or Landsat-3 (LS3). The profile is estimated between days 133 and 197. The estimation is based on the examinations of profiles in other studies in which the wheat growth stages have indicated that maximum greenness can be expected about the booting stage of growth (Feekes stage 10), followed by a decrease in greenness through ripening. Since greenness can thus be used as an indicator of green growing plants, it is important to separate the atmospheric effect, as the profile clearly would be different in uncorrected satellite data. This is significant in techniques such as that proposed by Badhwar (ref. 5) which utilize the spectral profile of a crop to establish an emergence date.

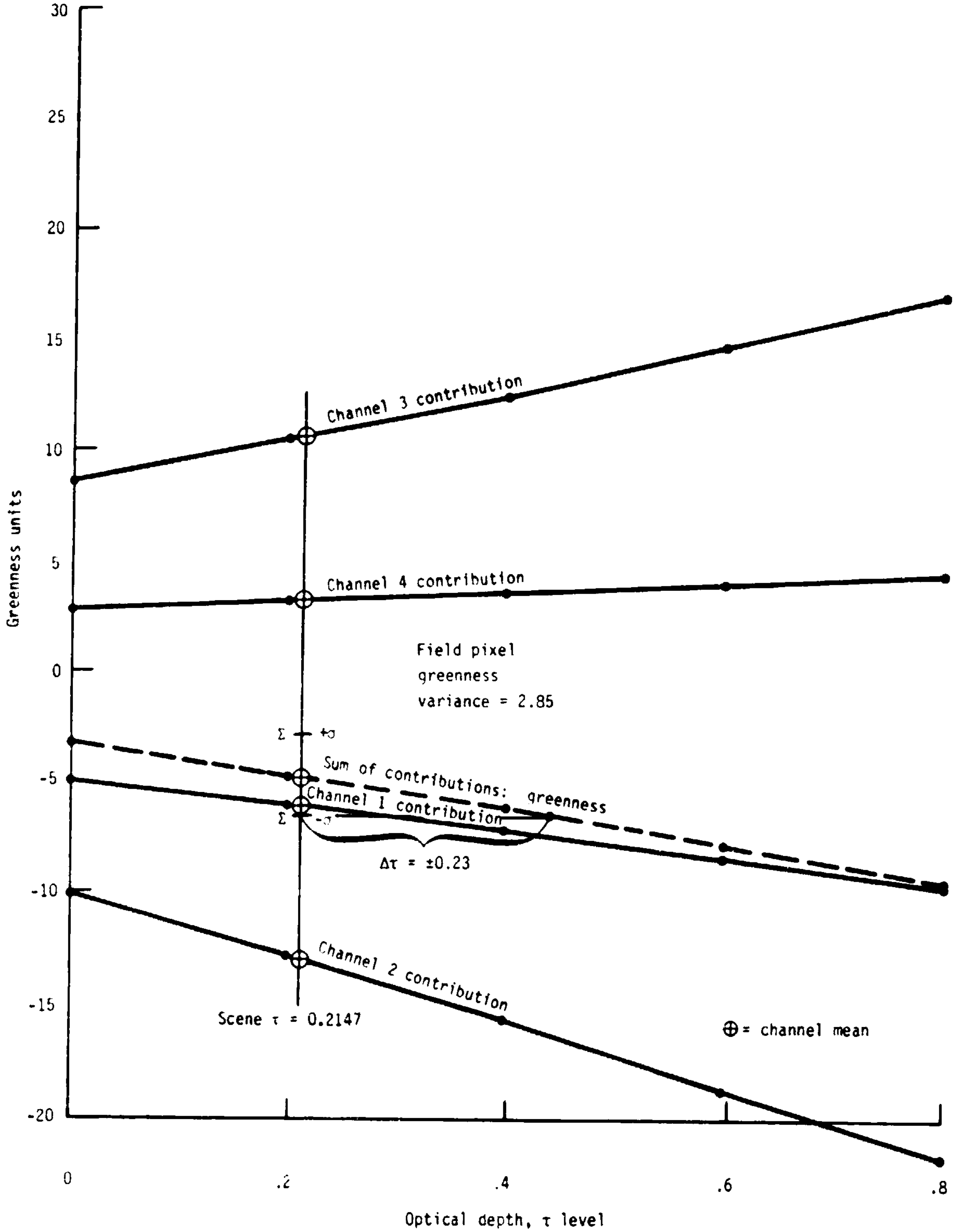


Figure 5-1.- Channel greenness contribution with increasing τ (day 115, near emergence).

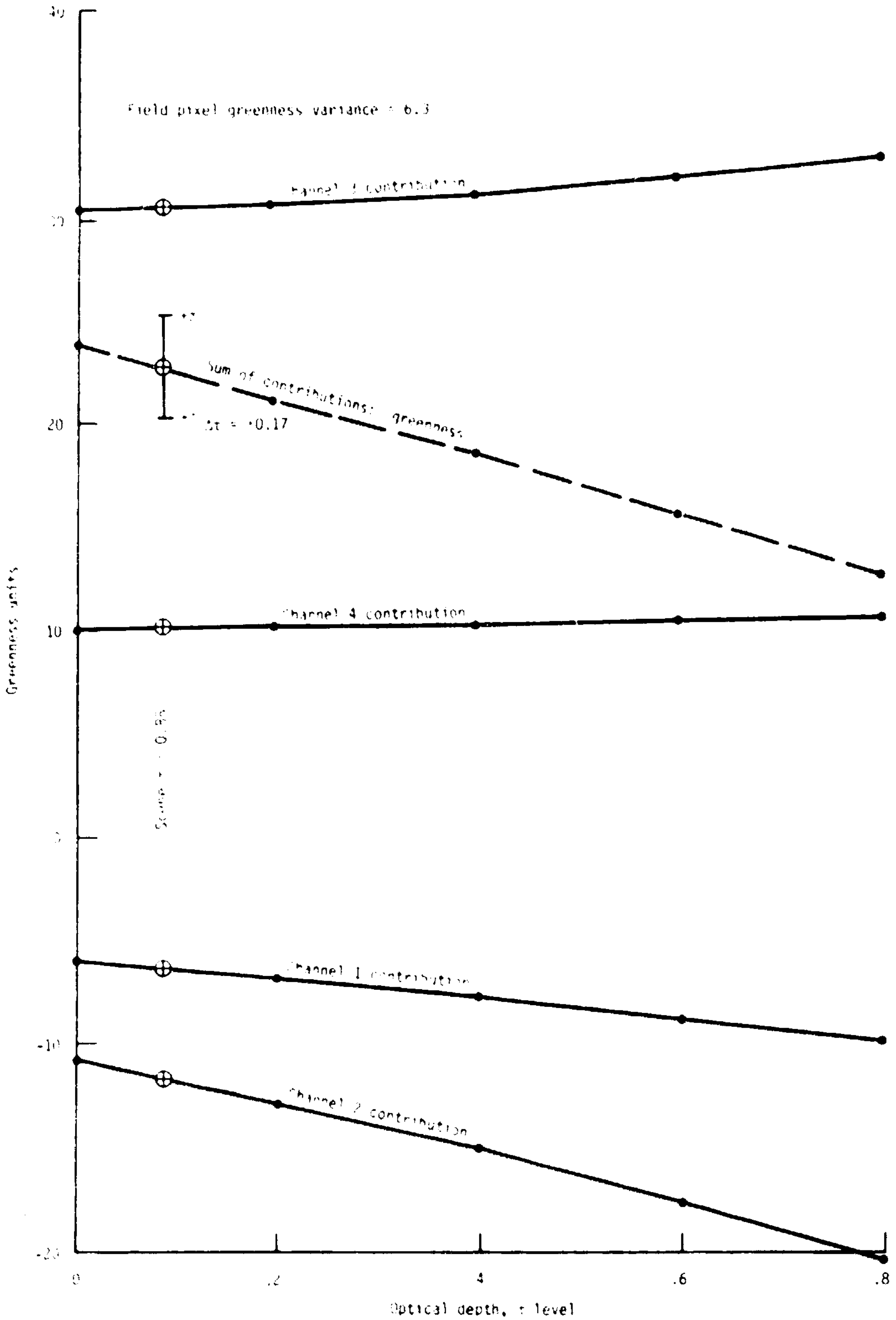
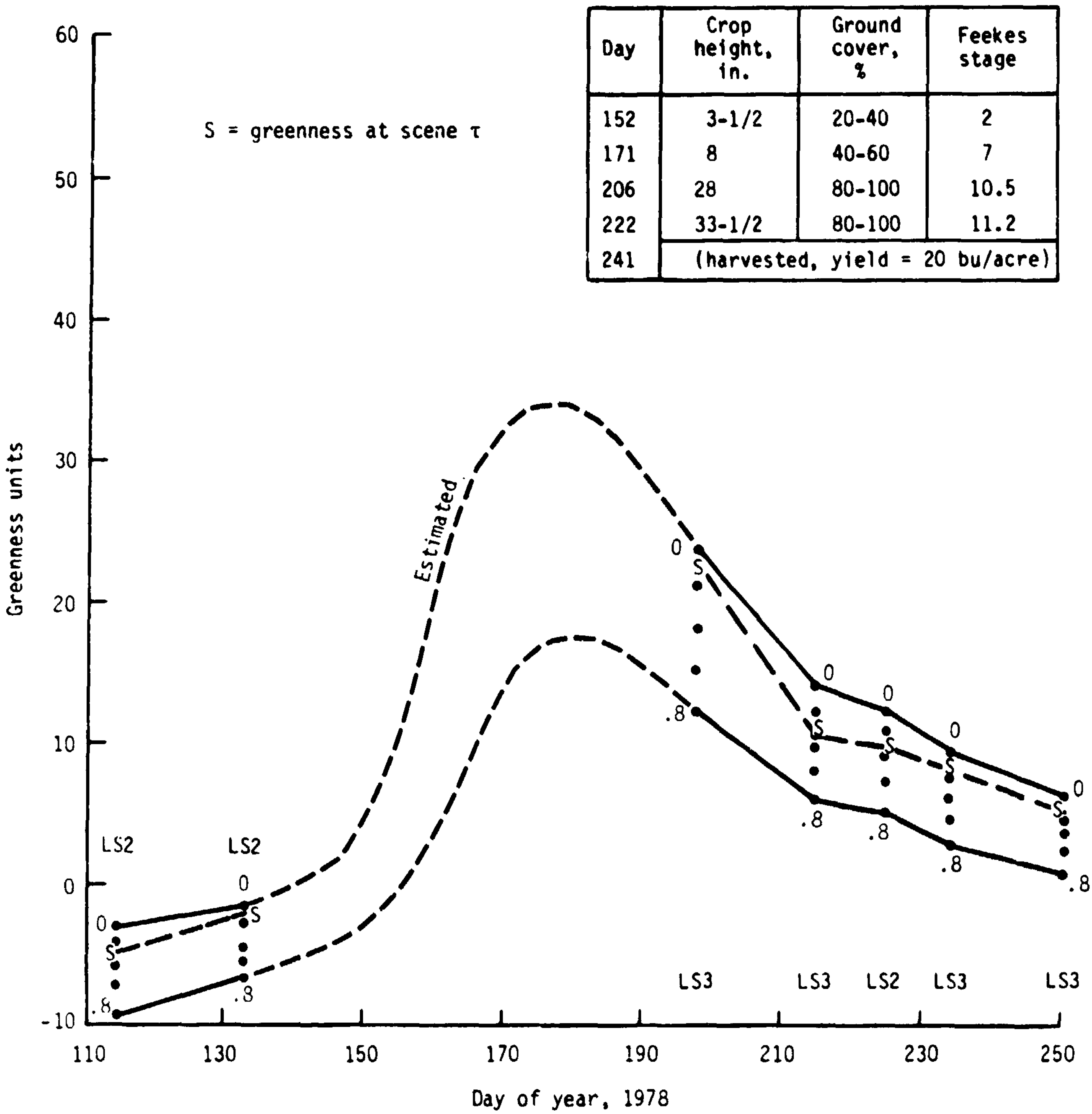


Figure 5-2.- Channel greenness contribution with increasing τ (day 197, near ripening).



Day	Crop height, in.	Ground cover, %	Feekes stage
152	3-1/2	20-40	2
171	8	40-60	7
206	28	80-100	10.5
222	33-1/2	80-100	11.2
241	(harvested, yield = 20 bu/acre)		

Figure 5-3.- Greenness profile with variable haze layers.

Since changes in greenness values can be used as crop identification parameters, the slope of the curve between the scene τ's indicated by the S's on days 197 and 215 becomes a function of the differences in τ which could exist on these two days. Thus, without knowledge of the haze levels, the slope variability parameter becomes less significant.

6. HAZE EFFECTS ON BRIGHTNESS

The brightness transformation (appendix B), consisting of all positive terms in all four channels, was applied to the field 3 data sets at each of the five simulated haze levels. Figures 6-1 and 6-2 show plots of brightness and contributions of the four channels to brightness. Note that the sum of the contributions, brightness, is plotted against the offset scale at the right: in both figures, the brightness increases with increasing τ levels.

Figure 6-3 shows the brightness profile through the wheat-growing year. Each data point on the profile was computed by applying equation (1) (section 2) to the data set of simulated field means at each acquisition date. Lines connecting each of the 0.0 to 0.8 τ haze levels describe a profile of constant τ. The profile is estimated between day 133 and day 197 and was constructed similar to the method used in the greenness estimate in figure 5-3. The increase in brightness at day 233 was seen in the ripening stages just prior to harvest in most of the wheat fields in this segment during 1978. However, this increase in brightness was not seen in southeast North Dakota during this growth stage in the previous year.

It is unclear, because of unpredictable early and late season changes, whether brightness patterns would be useful in crop analysis. Figure 6-3 shows that brightness is sensitive to haze. It can be seen that a brightness profile would be changed significantly if there were changes in τ from acquisition to acquisition, which were as large as the variability (0.053 to 0.368) found in this set of acquisitions.

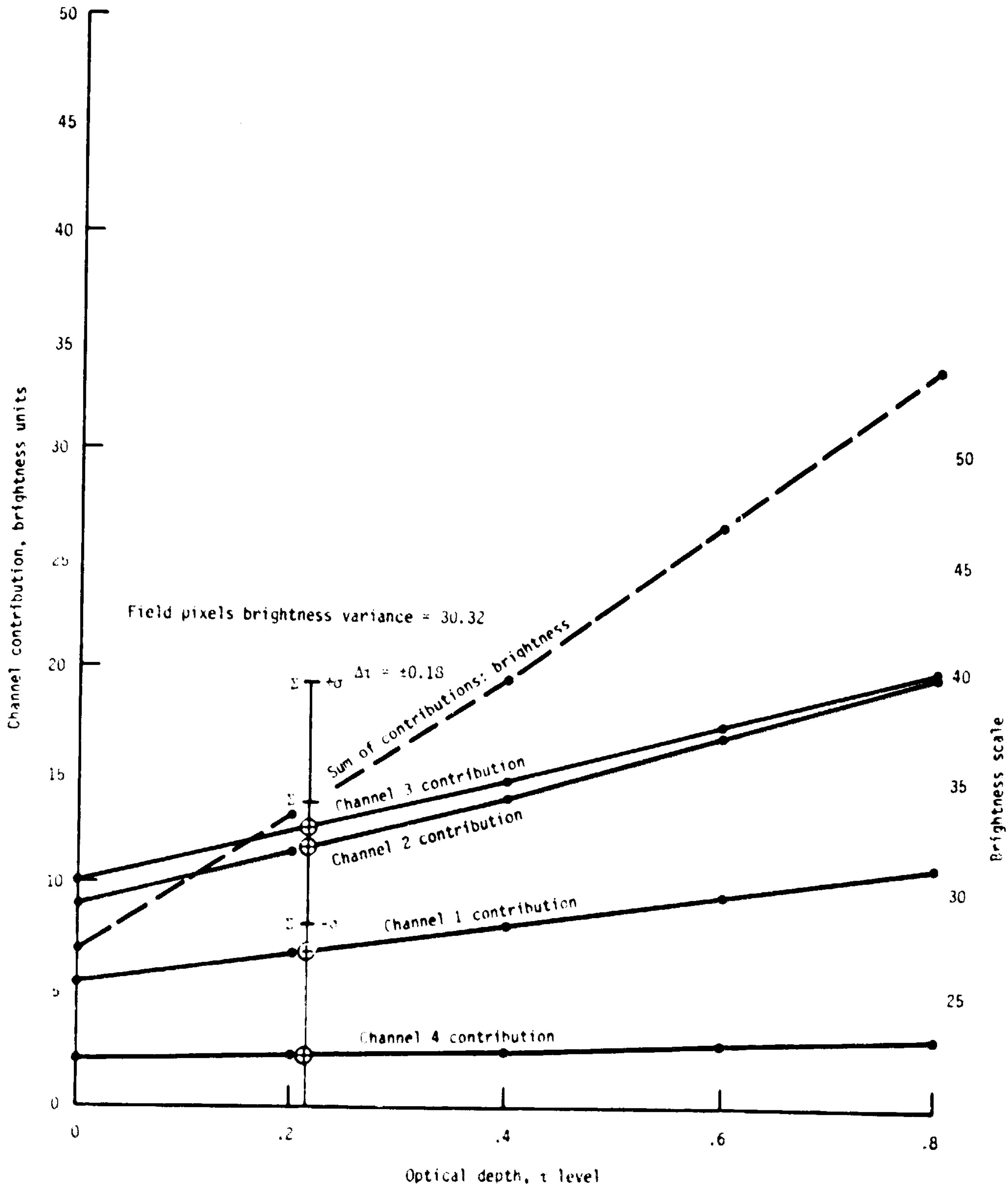


Figure 6-1.- Channel brightness contribution with increasing τ (day 115, near emergence).

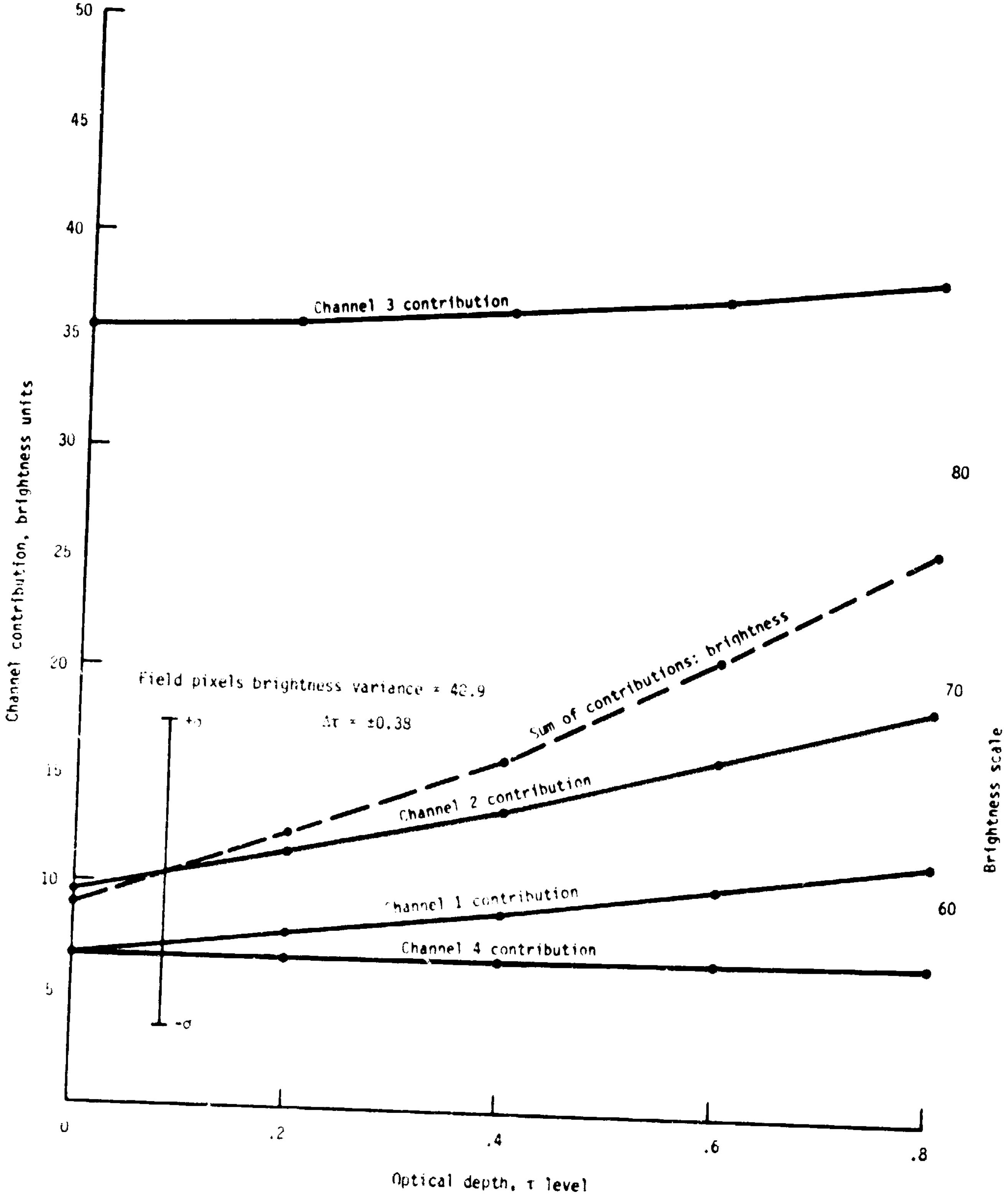


Figure 6-2.- Channel brightness contribution with increasing τ (day 197, near ripening).

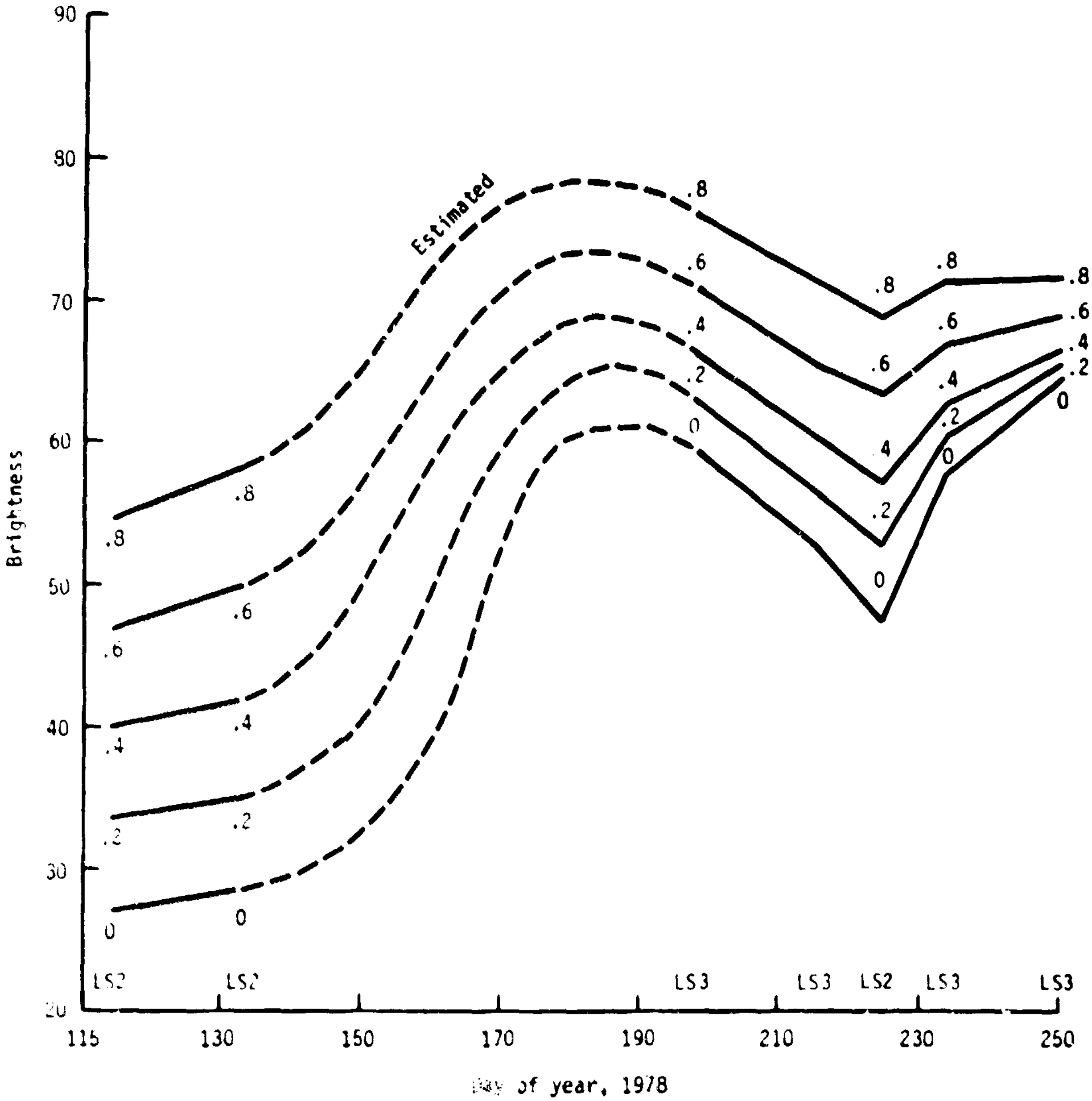


Figure 6-3.- Brightness profile with variable τ.

7. HAZE EFFECTS ON GREENNESS-BRIGHTNESS PLOT

Figure 7-1 shows the greenness-brightness plots of the means for special field 3 on each Landsat acquisition date. For each day, a line is shown which gives the results for simulated haze levels. The results all correspond to the same set of background reflectances that were calculated using ATCOR for day 197.

The positions of the scene brightness and greenness, as computed with the original data and not corrected for any changes in τ or background reflectances, are indicated by a circled S. These positions are connected temporally to show the trend of the greenness-brightness track through the growing year. It will be seen that the S is sometimes offset from the lines. This indicates that the scene background reflectance is slightly different.

An examination of this figure emphasizes that greenness-brightness plots can be changed radically if variations in haze occur over a segment during the crop growing season. Thus, it is apparent that MSS data from a sequence of acquisitions over a particular site should be standardized to a specific haze level before data transformation.

The results of this analysis agree with those of Davé (ref. 6) whose analysis of a wheat field's reflectance data with models 2, 3, and 4 (increasing haze) shows brightness increases and similar greenness decreases.

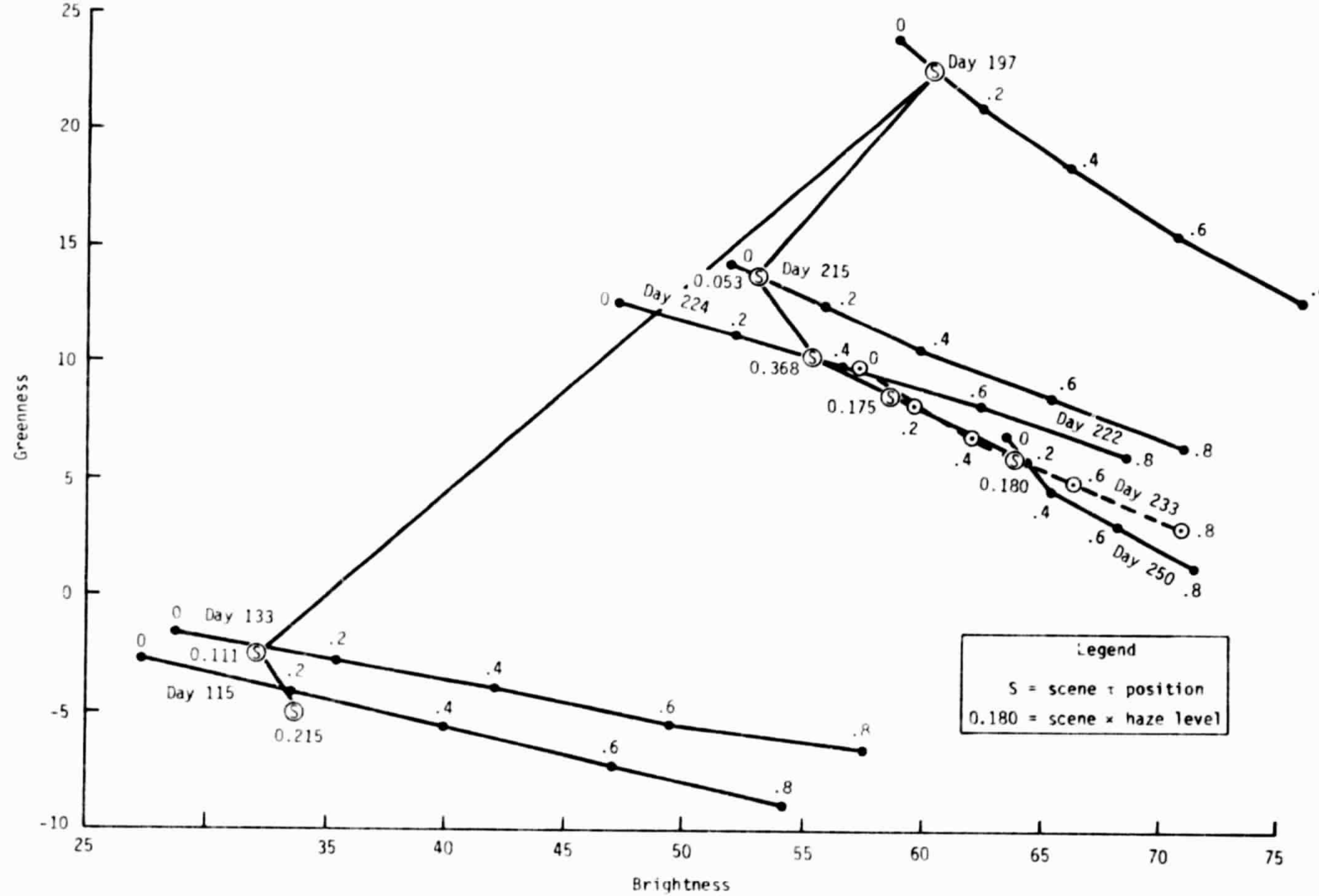


Figure 7-1.- Greenness-brightness plots with variable haze layers on various acquisition dates.

8. HAZE EFFECTS ON YELLOWNESS

The yellowness transformation (appendix B) was applied to the means from special field 3. The values were derived from the spectral data sets which were representative of each of the five haze levels. The computations were made for each of the seven acquisition dates for segment 1811.

The results presented in figure 8-1 indicate that, with a 44° to 56° sun angle, haze causes a change in yellowness and that the increments of haze levels cause an almost linear change in yellowness. It is significant that the sequence of Landsat-3 values changed gradually during this growing year and apparently was not affected significantly by changes in crop stage. Isolation of the Landsat-3 data from day 197 to day 250 shows a tendency to become less negative but still within a range to be considered as a measure of haze level.

The offset of the Landsat-2 data on day 224 indicates that the Wehmanen coefficients used to make the Landsat-3 data simulate Landsat-2 data do not perform well in the yellowness computations. This offset is noted on this date in the other spring wheat fields in this segment.

The results of this analysis again agree with Dave (ref. 6, fig. 8-1) where, at a 30° sun angle, yellowness is seen to decrease with increasing haze. Some segments are seen by Landsat on consecutive days. On the first day, the segment is viewed to the far right of the satellite track; and, on the second day, the segment is seen to the far left of the track. (Each of the data acquisitions has been annotated with an R or an L to designate whether data were viewed to the right or left of the satellite track, respectively.) This small change in viewing angle, even though the sun illumination of the segment is almost the same, produces a measurable difference in pixel values. This difference is usually ignored in imagery analysis. This sequence of plots, however, does not indicate a noticeable trend that the data from the left side of the track differ from the data from the right side of the track. A much larger sampling of data is needed to establish the significance of the viewing angle from Landsat.

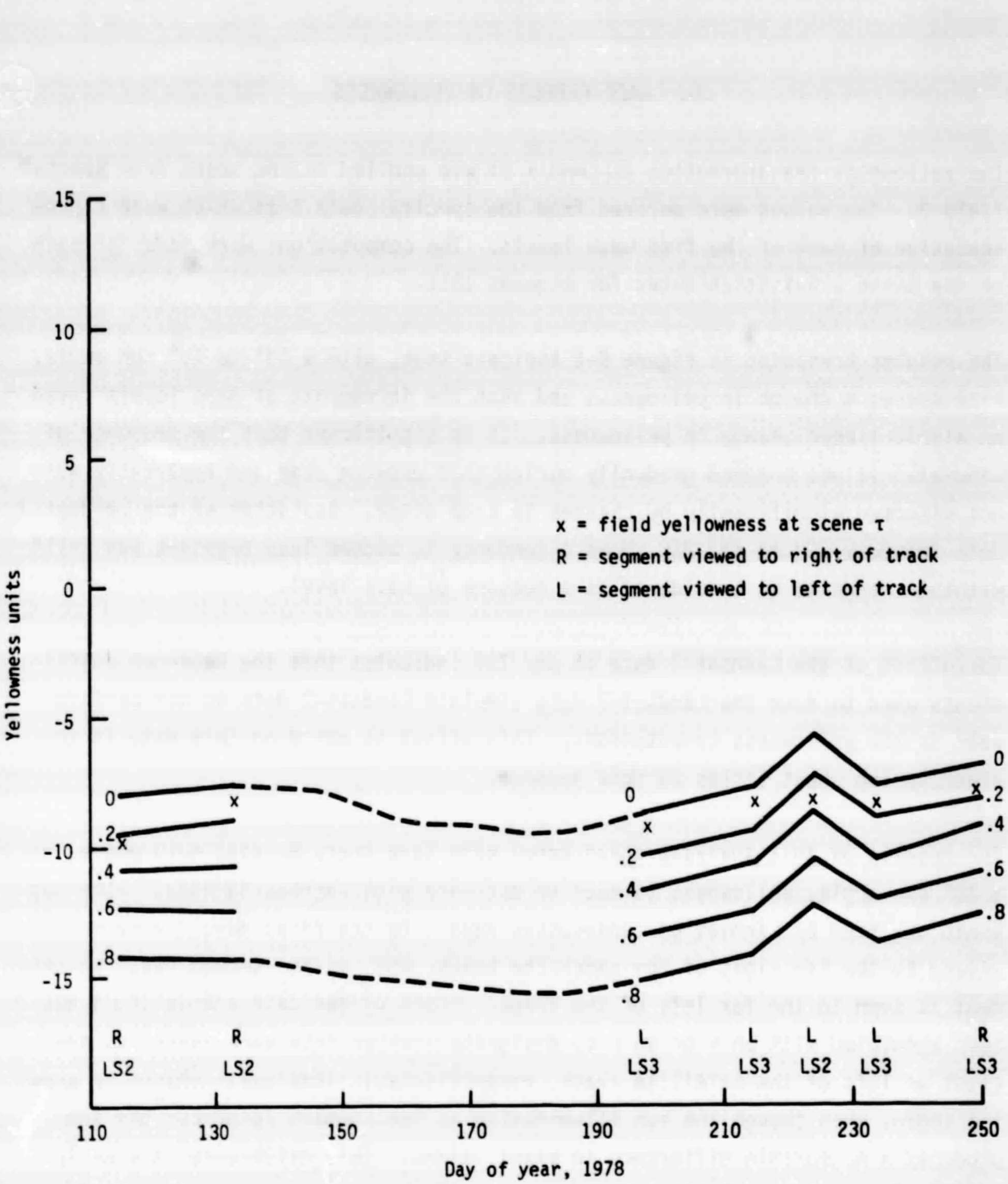


Figure 8-1.- Yellowness profile with variable τ.

9. HAZE EFFECTS ON NONE-SUCH

Computations of none-such by use of the none-such transformation (appendix B) were performed on data in the same manner as were greenness, brightness, and yellowness. The results, which are presented in figure 9-1, indicate a definite difference between Landsat-2 and Landsat-3 data. The Landsat-2 plots of none-such at the various haze levels show either a decreasing none-such with increasing τ or a completely mixed trend (i.e., consecutive 0.2 haze levels were not ordered in sequence; see day 115).

The Landsat-3 plots at various τ levels show an irregular but significant increase in none-such with increasing τ. This difference is indeed due to the application of the Wehmanen coefficients to make the data from the two Landsats equivalent. This is shown by computing none-such for Landsat-3 using data prior to the Wehmanen conversion and noting that the distribution is the same as that occurring for Landsat-2 data. The non-Wehmanen limits are shown as x plots using the scale at the right of figure 9-1.

No interpretation of none-such data is known to have been made in these or in any previous studies.

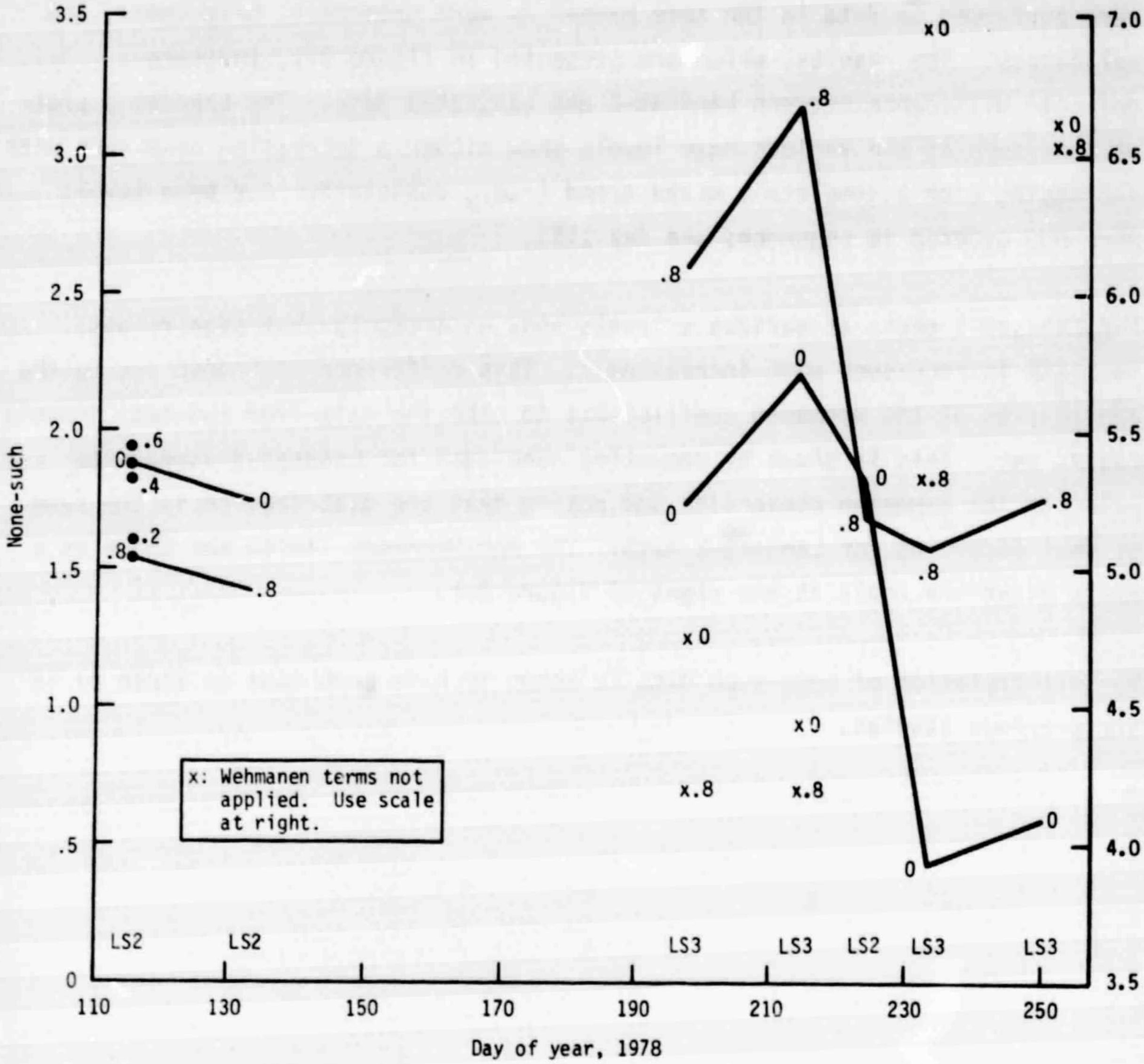


Figure 9-1.- None-such plots with variable τ.

10. ATMOSPHERIC CORRECTION PROGRAM PERFORMANCE

The ATCOR program provides a technique to estimate the haze level and to compute average reflectance for a given Landsat acquisition. These background reflectance values vary throughout a growing season but remain within a specified range of values which depend on soil color, soil moisture, soil character (rocky, clay, etc.), land use, water coverage, and deciduous growth.

The greatest weakness of the ATCOR program is the lack of knowledge of the range of background reflectance values for an area in the four Landsat channels. These background reflectances are related to a minimum reflectance term used in ATCOR processing and are referred to a baseline τ level (positive, but not necessarily zero). However, by processing with a standard minimum reflectance term, ATCOR provides a scene τ estimate which must be related to an unspecified baseline level. Iteration could produce a satisfactory merge of background reflectance with minimum reflectance; operationally, this is not feasible. However, the significant product is the series of scene τ estimates at each acquisition time with the ability to reduce all data sets to a specified simulated τ level. The transformations produced from the ATCOR-processed data then should reflect realistic time profiles. The values of the profiles would be a function of standardized background reflectance with a uniform haze level through the profile, not necessarily related to a zero τ level.

Another capability of the ATCOR program is to provide coefficients to change data to reflect the standard sun-angle illumination of a segment. Thus, the effects of the variable sun elevation angle through the year can be eliminated. This will be important where multiseasonal crops are investigated, as is the case when two rice crops in Texas are planted and harvested consecutively in the same year, or when crops are grown at all times of the year in the equatorial belt.

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APPENDIX A

LANDSAT DATA SET FOR SEGMENT 1811, KINGSBURY COUNTY, SOUTH DAKOTA

APPENDIX A

LANDSAT DATA SET FOR SEGMENT 1811, KINGSBURY COUNTY, SOUTH DAKOTA

Acquisition, Julian date in 1978	Data from Landsat	ATCOR optical depth of haze in scene
115	2	0.215
133	2	.111
197	2	.088
215	3	.053
224	2	.368
233	3	.175
250	3	.180

APPENDIX B

LANDSAT-2 DATA TRANSFORMATIONS

APPENDIX B

LANDSAT-2 DATA TRANSFORMATIONS

$$\begin{bmatrix} X_i & = \text{pixel value} \\ i & = \text{channel} \end{bmatrix}$$

Greenness: $y_2 = -0.283 \times x_1$

$-0.660 \times x_2$

$+0.577 \times x_3$

$+0.388 \times x_4$

Brightness: $y_2 = 0.332 \times x_1$

$+0.603 \times x_2$

$+0.676 \times x_3$

$+0.263 \times x_4$

Yellowness: $y_2 = -0.900 \times x_1$

$+0.428 \times x_2$

$+0.076 \times x_3$

$-0.041 \times x_4$

None-such: $y_2 = -0.016 \times x_1$

$0.131 \times x_2$

$-0.432 \times x_3$

$0.882 \times x_4$

APPENDIX C

THE WEHMANEN TRANSFORMATION TO BE APPLIED TO LANDSAT-3 DATA

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THE WEHMANEN TRANSFORMATION TO BE APPLIED TO LANDSAT-3 DATA

The Wehmanen terms are multiplied by the Landsat-3 data to simulate Landsat-2 data:

Channel	Wehmanen terms
1	1.161
2	1.230
3	1.246
4	1.062

Example: $1.161 \quad L3_1 = L2_1$,

where $L3_1$ = Landsat-3 channel 1 data and $L2_1$ = Landsat 2 channel 1 data.

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